Determining Differentiated Services Network Pricing Through Auctions

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Abstract. Over the years, quality of service (QoS) has attracted attention from researchers. How to guarantee QoS to customers despite the rapid change of the network status is the main concern. Pricing provides an effective economic means of congestion control and revenue generation. We examine pricing as an effective strategy for revenue management in DiffServ networks. In this paper, we propose an auction scheme to allocate network resources efficiently so as to maximize service provider's revenue. We examine an auction mechanism that provides multiple options for customers to bid on the resources that they require as well as the price they are willing to pay. The service provider acts as an admission control unit in the sense of deciding the admission price and service provided for each class. We target the goal of maximizing a service provider's revenue through auctions.

1 Introduction

Traditionally only best effort service is employed in Internet. Under this system, all clients pay the same amount of money to get the same kind of service. When the network is congested, the service provider randomly drops packets. There is no guarantee on any specific services for the customers. As the Internet moves from only providing best effort service to a differentiated service network, a new design of pricing and resource allocation strategy is desired. Pricing has been shown to be an effective and efficient way for service improvement and revenue generation.

There are several pricing approaches, e.g. a cost based scheme, an optimization based methodology, edge pricing, auctions and so on [4, 6, 7, 8]. Despite the variety of the strategies, the basic idea is that the appropriate pricing policy will provide incentives for users to behave in ways that improve overall utilization and performance of the network. An auction is a mechanism that allows for the submission of bids that guide, rather than explicitly specify the choice of service and price to fulfill the buyer's needs. Auction is a decentralized mechanism for efficiently and fairly sharing resources inside a network [3].

We study the revenue maximization problem of a price-based resource allocation scheme for Differential Service (DiffServ) data networks [2]. Best Effort

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(BE) is the default per hop behaviour for best effort traffic and some minimum amount of bandwidth will always exist for BE. How to allocate the remaining bandwidth for Expedited Forwarding (EF) and Assured Forwarding (AF) is an open question. Therefore, in our model, we deal with a two-class EF and AF ratio resource allocation problem.

In this paper, we consider a scenario where customers bid and specify price and service required. There are two parts in the price bids. One is called base price, which corresponds to the minimum bandwidth requirement. The other is price sensitivity coefficient, which measures the payment for any extra resource allocation other than the minimum bandwidth requirement. The auctioneer tries to maximize the service provider's revenue by selectively accepting bids. Auctions happen at fixed time intervals. The service provider calculates a minimum bandwidth they would provide to each class based on all the bids, with the goal of maximizing the service provider's profit.

2 Related Work

"Smart Market" [5] opens the door of using an auction mechanism to solve the Internet pricing problem. The main idea of "smart market" is to find a way to deal with modeling the pricing to manage congestion, encourage network growth and guide resources to their most valuable use. The threshold price (which is calculated as a marginal cost when the network gets congested) reflects the resource costs and offers users incentives to pay more for a valuable service or release the resources to others. Even though "smart market" creates the ability to allocate Internet resources in an economic context, practically it is very hard implement in a real network. To offer a bid on each traffic packet yields too much overhead in the network and bursts are difficult to handle. Also, how fast the users react to the auction results could fluctuate the price rapidly and irregularly.

Basar and Srikant [1] assumed that the price of a per-bandwidth unit is fixed to users and the transmission rate of each user is a function of network congestion and price-per-unit bandwidth. They verified that as the number of users increases, the optimal price-per-unit-bandwidth increases.The utility function that they adopt is U=$w_i$logx_i (w_i is a sensitivity coefficient and x_i is the bandwidth). They use w_i's value as an admission criteria. Users with smaller w_i's are dropped out of the network. We consider this a valid strategy to keep admission simple but effective.

3 Problem Formulation

To make a bid in an auction, a customer needs to specify three values. First of all, customers are required to bid the minimum service that they demand (the bandwidth in our case) and the corresponding price they would like to pay. This price is called base price, to support the basic service. Besides this, if customers also need more bandwidth than the minimum requirement, they need to pay for this extra part also. This happens when customers can tolerate the minimum resource allocation, but prefer even more if possible. For example, when a video conference application is being transmitted, there is a minimum resource requirement to support it. If extra bandwidth is available, customers may be able to use it for better quality, thus they need to specify their valuation for extra bandwidth. For the sake of fairness, we assume the base price and minimum resource allocation dominate. In order to prevent the link capacity from being eaten up by those extra bandwidth requests, a logarithm function is employed here. It is described as: $W_j \log \frac{X_j}{L_j}$, where X_j is the bandwidth allocation to customer j and L_j is customer j's minimum bandwidth requirement. When $X_j = L_j$, there is no extra cost other than the minimum. If $X_j > L_j$, the amount of charge depends on value W_j, which comes from customers' bids. We call W_j the price sensitivity coefficient. Customers can bid W_j=0, which indicates that they do not want any bandwidth beyond the minimum. The general revenue function is:

$$U_{kj} = U_{0j} + W_j \log \frac{X_{kj}}{L_{kj}}$$

where U_{kj} is the revenue from client k in class j. U_{0j} is class j's base price. W_j is the sensitivity for class j, which stands for customers' willingness of paying for more bandwidth than the minimum requirement. X_{kj} is the bandwidth assigned to client k, class j. L_{kj} is the minimum bandwidth required by client k.

Customers bid for the base price, sensitivity coefficient and minimum required bandwidth. The objective is to maximize the service provider's revenue, subject to the system's available resources.
The mathematical formulation is as follows:

Decision variables:

$$Z_{ij} = \begin{cases} 1; \text{if client i is admitted to class j} \\ 0; \text{otherwise} \end{cases}$$

U_{0ij}: base price from client i in class j;
X_{ij} : bandwidth obtained by client i in class j;
L_{mj} : minimum bandwidth for class j;
W_j : price sensitivity for class j;
X_j : bandwidth assigned to each individual client in class j;
Objective function:

$$max \sum_{j=1}^{2} \sum_{i} (U_{0ij} + W_j \log \frac{X_{ij}}{L_{mj}}) * Z_{ij} \tag{1}$$

Subject to:

$$\begin{cases} \sum_{j=1}^{2} \sum_i X_{ij} <= Q \\ X_{ij} \geq L_{mj} - (1 - Z_{ij}) * M \\ W_j \leq W_{ij} + (1 - Z_{ij}) * M \\ X_{ij} \geq V_i - (1 - Z_{ij}) * M \\ X_{ij} \geq X_j - (1 - Z_{ij}) * M \\ X_{ij} \leq 0 + Z_{ij} * M \\ X_{ij} \geq 0; L_{mj} \geq 0; W_j \geq 0 \\ X_{ij} \leq X_j \end{cases}$$

Parameters:
Q : total bandwidth
V_i : minimum bandwidth required by client i
M : a very large positive number

The scenario is that all the customers propose values: U_{0ij}, W_{ij} and L_{ij} and we have to decide which flows should be admitted for each class with the objective of maximizing the service provider's revenue. For each class j, we adopt the minimum U_{0ij}, W_{ij} as our U_{0j}, W_j and the maximum L_{ij} as our L_j. All flows in one class are assigned the same amount of bandwidth.

4 Optimal Solution

We notice that every flow in one class has the same threshold (U_{0j}, W_j, L_j) and flows within the same class will obtain the same bandwidth. Suppose that class j's assigned bandwidth is Q_j, each flow gets its own share of Q_j/m_j where m_j represents the number of flows admitted into class j, and generates the same revenue. We solve the problem using the objective function and corresponding constraints formulated as follows:

$$\max \textstyle\sum_{j \in N} \; m_j * (U_{0j} + W_j \log \frac{Q_j}{m_j L_j}) \tag{2}$$

$$\text{subject to:} \qquad \textstyle\sum_{j \in N} Q_j = Q. \tag{3}$$

The solutions are obtained by Lagrange relaxation:

$$Q_j = (m_j W_j)/(\sum_{j \in N} m_j W_j) * Q, \ \forall j \in N. \tag{4}$$

Therefore, given (m_j, U_{0j}, W_j and L_j), we can obtain Q_j as in equation (4). According to auction policy, $U_{0j} = \min\{U_{0ij}, i \in M_j\}$, $W_j = \min\{W_{ij}, i \in M_j\}$ and $L_j = \max\{L_{ij}, i \in M_j\}$. This also implies that each combination (U_{0kj}, W_{mj} and L_{nj}), where $k, m, n \in M_j$, provides a candidate value set for class j. Therefore, based on the bids in class j, we make all combinations in terms of U_{0ij}, W_{ij} and L_{ij}. For each combination, which corresponds to one predetermined set of value (U_{0j}^*, L_j^* and W_j^*) for class j, we sort out all the flows such that $U_{0ij} \geq U_{0j}^*$, $W_{ij} \geq W_j^*$ and $L_{ij} \leq L_j^* \;\; \forall i \in M_j$. Record the number as k. So each combination has a k value associated with.

Now, for each class $j \in N$, starting from m_j=1 and L_{1j}, check all the combinations of (U_{0ij}, W_{ij}). From these, the effective ones are those with $k \geq m_j$. From our previous assumption that U_{0ij} is a dominant pricing factor, which is given the highest priority to choose the combinations with largest U values. From among the largest U value set clients, choose the one with the highest W value. Until now, we obtained values of U_{0j}, W_j and L_j for each class j. Then we have all inputs ($U_{0j}, m_j, L_j, W_j \; \forall j \in N$) for the solution of equation 2, and $Q_j \; \forall j \in N$ can be calculated as in equation 4. We have specified earlier that each admitted flow in one class shares the same amount of bandwidth and this bandwidth has to be greater than or equal to their bids. We are using that property to check the validity of each possible solution. If and only if $Q_j/m_j \geq L_j\ \forall j \in N$, the solution is a qualified candidate. If so, by using those values as well as U_{0j}, the total revenue is computed. Otherwise, this set of solution values is abandoned. Following the same steps by changing the value of m_j and L_j, we can obtain all the possible feasible solutions. Finally, the solution with the highest total revenue is optimal.

So now we have the optimal solutions for calculating the best thresholds as well as the assigned bandwidth to each class and client, in terms of maximizing service provider's revenue. The next question is how should we use the thresholds to admit new flows. We know that the auction occurs with a fixed time interval. During that interval, when new customers want to join in, they present their bids. Then, if it is possible to admit them, they can get into the network. Otherwise, they have to wait for the next auction to take place. How does the service provider decide if letting them in is going to benefit him or not? We propose the following property to explain what procedure the service provider should follow in order to make a good judgment.

Property 1. If Q_j and (U_{0j}, W_j, L_j) are fixed, as long as $Q_j/m_j > L_j$, U_j is a strictly increasing function of m_j.

Proof:

The revenue function is:

$$U_j = m_j * U_{0j} + m_j * W_j \log \frac{Q_j}{m_j L_j}. \tag{5}$$

Its derivative is:

$$\frac{\partial U_j}{\partial m_j} = U_{0j} + W_j \log \frac{Q_j}{m_j L_j} - W_j. \tag{6}$$

Since $Q_j/m_j > L_j$, and U_{0j} is greater than W_j (which is our assumption), $\frac{\partial U_j}{\partial m_j}$ is always greater than 0. That guarantees that U_j is a strictly increasing function of m_j.

Using property 1, the service provider can increase the revenue by admitting any new flow i into class j as long as $L_{ij} < L_j$, $W_{ij} > W_j$ and $U_{0ij} > U_{0j}$. So, after the bidding thresholds have been decided, property 1 gives the service provider a guideline as to how to admit new flows.

5 Simulation and Analysis

As an example, we may assume that the Best Effort (BE) class is charged $35 per client per month. Divide that by days and minutes, 0.00135 cents per minute needs to be paid for BE traffic. Let a mcent (or a unit) be equal to 1/1000 cents, so the charge for BE is 1.35 mcents. Based on this, we define EF traffic's price as twice as much as BE's and AF's price as 1.5 times as much as BE's. These values

Table 1. The assumptions that are used in the simulations

	Parameters		
	FV [1]	MV [2]	SD [3]
EF	2.7 *mcents*	[2.7 - 5.4]*mcents*	[1 - 2]*mcents*
AF	2.0 *mcents*	[2.0 - 4.0]*mcents*	[1 - 2]*mcents*

are the service provider's price thresholds for each class. Any customer who bids lower than the threshold price will be rejected. The customers' valuations for EF and AF are assumed to be normally distributed.

In the flat rate scenario, a customer is admitted if and only if his valuation (which is same as the bid in the auction context) is greater or equal to the fixed price set by the service provider. The revenue is the number of customers multiplied by the price.

All the parameters given in Table 1 are used to determine the revenue generated by service provider. The customers' mean valuation (MV) and standard deviation (SD) are within a fixed range instead of a fixed number. This is because we vary the MV and SD in the simulations to show that our algorithm is not sensitive to how those parameters are chosen.

To compare the optimal resource allocation results with traditional flat rate pricing, we set the flat rate as an independent variable. We ran our algorithm with a fixed set of parameters and compared the results with the revenue generated by a fixed rate pricing scheme. The rate for each class changes within the range of (20%–220%)× MV where MV is the customers' mean valuation. We want to test and show that the algorithm's performance is not sensitive to how we choose the parameters. In other words, we want to show the auction scheme that we propose is robust. We vary the offered network load from 70%, 100% to 140% and vary the customers' mean valuations. Figure 1 shows the revenue comparison between our algorithm and flat rate pricing when the customers' valuations are normally distributed with a mean of 2.7 mcents and a standard deviation of 1 mcent for EF and a mean of 2.0 mcents and standard deviation 1 mcents for AF. The subgraphs (a), (b) and (c) show the results with network load at 70%, 100% and 140% respectively. We then vary customers' mean valuation to 4.0 mcents for EF and 3.0 mcents for AF (standard deviation remains the same as before). Figure 2 shows how the network behaves when the mean valuation changes to 5.4 mcents for EF and 4.0 mcents for AF. From all the results, we can see that the auction scheme predominantly outperforms fixed pricing. In all cases, auctions generate more revenue than the fixed rates. The revenue generated by the fixed rate pricing has similar curves because when the fixed rate is very low, even when it wins all the customers, the sum of the payments is low and when the rate is high, it loses customers which also reduces the service

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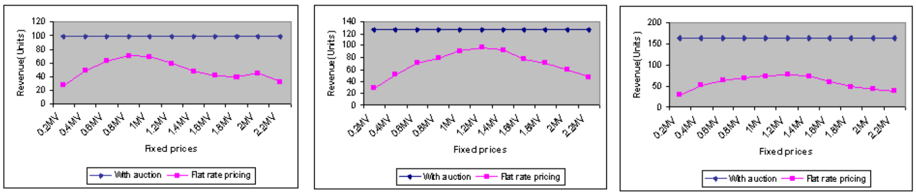
[1] FV: Floor Value

[2] MV: Customers' Mean Valuation

[3] SD: Customers' Standard Deviation

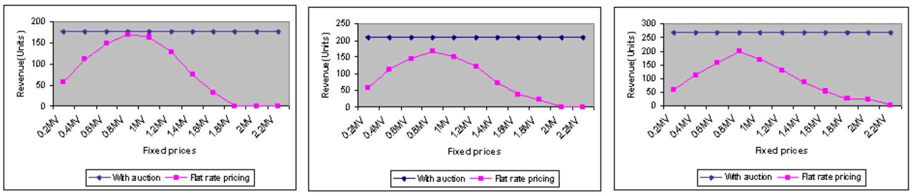


Network load = 70%
(a)

Network load = 100%
(b)

Network load = 140%
(c)

Fig. 1. The revenue comparison (customers mean valuation is 2.7 and 2.0 mcents)



Network load = 70%
(a)

Network load =100%
(b)

Network load = 140%
(c)

Fig. 2. The revenue comparison (customers mean valuation is 5.4 and 4.0 mcents)

provider's profit. In some cases, the curve fluctuates. This is because when the fixed rate increases, the number of admitted customers decreases. That causes the revenue function to be nonlinear. Also, it shows the same trend that as the network load increases, the gap between auctions and fixed price increases. This shows that auctions performance improves when the system gets congested. This is because auctions offer the service providers more options to choose the most valuable customers and drop others. It also causes customers to compete for bandwidth by raising their prices.

6 Conclusion

We considered a DiffServ network and studied the problem of maximizing the service provider's profit using pricing. We presented a novel pricing strategy of maximizing the service provider's revenue based on clients' bids of price as well as desired service. The scheme proposed in this paper gives customers the option to choose how much they want to pay for along with their required services. Our solution provides the thresholds for each service class according to network resource availability. The thresholds can also be used as a future reference for admitting new clients. We compared the revenue generated by auction and fixed pricing. Our auction scheme generates the best result even when varying the parameters. Our results show that the auction strategy beats the commonly used fixed rate pricing scheme.

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